THE DRIFT AND GEOLOGIC TIME.

ASSUMING the correctness of the ice-sheet or glacier theory of the origin of the drift which, according to one supposed to be of high geological authority,[1] "has passed from the region of hypothesis to that of demonstration, and should form the basis of all reasoning on the subject," there are still many problems that are open to discussion and in regard to which writers widely vary in their opinions and statements. One of these is the lapse of time between the beginning and the end of the period, that portion of geologic time required to prepare for and lay down the drift deposits and to return to present climatic and physical conditions. Of late years there has been a tendency in some quarters to reduce the estimated length of this period. According to Prestwich[2] 25,000 to 35,000 years would suffice for the whole period of formation and retreat of the ice-sheet. Professor Wright endorses this estimate,[3] and Warren Upham[4] even abbreviates it a little, allowing only 20,000 or 30,000 years for the actual glacial period, and 6000 to 10,000 years for the since intervening time. Becker,[5] figuring on astronomical data, thinks that conditions favoring the glaciation of the territory covered by the drift may have existed within 40,000 years, and presumably gives that as the probable outside figure for their occurrence.

On the other hand, perhaps the larger number of glacialists have allowed in their estimates very much longer periods. To say nothing of Croll, Ramsay, Geikie, and earlier writers, we

[1] Geol. Mag., new ser., Decade IV, Vol. IV, 75, February 1897. (Review of Croll's Life and Work.")

[2] "Geology," p. 534, 1888.

[3] Man and the Glacial Period, p. 364, 1895.

[4] Bull. Am. Geol. Soc., V, 99, 1894.

[5] Am. Jour. Sci., 3d ser., XLVII, 95–113.

have, amongst recent writers, R. Bell,[1] who thinks the estimates of the above-mentioned authors *not* excessive. Chamberlin[2] estimates the lapse of time since the Kansan epoch to be equal to fifteen times the lapse since the last epoch, which would give a high figure for the whole period on any tenable estimate of this last factor, and to this is to be added an undetermined number of years for the pre-Aftonian (Albertan) stage. Penck, at the recent Toronto meeting of the British Association, is reported to have allowed at least 500,000 years for the glacial epoch, including all the interglacial stages, and very recently F. B. Taylor,[3] in an article on the moraines of recession of the latest (Wisconsin) ice-sheet, gives as his estimate of the time required for the retreat of this single ice invasion from the latitude of Cincinnati to the straits of Mackinac, a period of from 75,000 to 150,000 years. Adding to this an equal lapse of time for its advance, and we have an estimate of 150,000 to 300,000 years for the whole time occupied by this most recent member of the drift.

In addition to the actual periods of the ice occupancy of the territory we have to reckon in the interglacial epochs of which there is considerable evidence, and which must materially add to the length of Pleistocene time. I have not seen many estimates of the time required by these, the most noteworthy one being that of Professor McGee, of the time required for the deposition of the forest bed overlying the earlier Iowa till. Taking for his unit the period of written history, the very least figure he gives for this formation is about 112,000 years, and this is far exceeded by his estimate of its possible maximum duration. The thickness of some of these intercalated beds would naturally indicate a considerable period for their deposition, but McGee's estimate certainly seems an extreme one, and is the more noticeable when considered in connection with the relatively very short allowance of time he has given for the ice invasions themselves, even allowing, as we should, that he is

[1] Bull. Am. Geol. Soc., I, 295.

[2] JOUR. GEOL., IV, 875, 1896.

[3] JOUR. GEOL., V, 1897, July–August.

considering only the peripheral portion of the ice-sheet and not its greatest development. The length of the interglacial epoch must in any case enter as a very important element in our estimates of the total time required for the deposition of the drift, and the limited data from exposures are at best more suggestive than definite in the information they convey as to this point.

With these divergent views as to geologic time it would not appear as if the glacier theory afforded a very satisfactory basis for reasoning upon this particular phase of the subject. There certainly seem to be decided difficulties in utilizing the drift phenomena for the measurement of geologic time, each apparently possible solution of the difficulty seeming to present still more impossible problems. Some of the estimates made appear to be compromises, therefore, or alternatives, accepted only as better than something else. Thus Prestwich and Wright find it easier to limit the duration of the glacial period than to admit the possibility of man having existed 80,000 years on the earth, or that the fauna or flora of today could possibly be the same as that of 240,000 years ago. The elements of individual prepossession and mental idiosyncrasy enter largely into the consideration of scientific questions, and all the more into such as this where the chances of legitimate difference of opinion are so ample.

It is the object of this paper to call attention to the method of calculating geologic time by the transportation of erratics, a method that has up to the present time hardly received the attention it deserves in the literature of the subject. It is at first sight a little remarkable that this should be the case. That some at least of those who have alluded to it appear to have discredited its value is also remarkable, as any method that adds any degree of certainty to our estimates ought to be regarded as a boon to science. While, as I shall attempt to demonstrate, it has its value even with the rather indefinite notions we have hitherto had as to the flow of continental glaciers, recent researches by Chamberlin and others on the Greenland ice-sheet have added very much to its importance and applicability. We

have by it at the present time the data which enable us to form a definite minimum estimate of the time required for the deposition of the drift in North America, on the presumption that this was done through the agency of land-ice, or glaciers. If it is assumed that the drift was water laid, either altogether or to any considerable extent, altogether different elements enter into and affect the calculation, but that is not the assumption of the present paper.

It is perhaps conceivable that the climatic conditions during the formation of the ice-sheet were such that it was deposited by precipitation simultaneously over the greater part of the area it occupied. The névé, in other words, might have been almost coterminous with the glacier, only a narrow external rim being excluded. The evidence, however, of motion throughout at least the greater part of its extent is afforded by the erratics many of which have traveled 600 or 700 miles or even more from their original beds. A bit of jasper conglomerate found south of Cincinnati must clearly have traveled from the north shore of Lake Huron, and fragments of Archæan or eruptive rocks found abundantly along the southern limit of the drift in Illinois could have had no nearer source than northern Wisconsin 500 or 600 miles away, if indeed they have not a still more northern origin. A bowlder or pebble from the north shore of Lake Superior, if found in southern Illinois, would have traveled nearly or quite 800 miles, and while I am not sure that any such have been identified, their occurrence there is altogether within the bounds of probability. Such erratics, according to the glacier theory, must have been conveyed as subglacial or intraglacial detritus and must have progressed with the ice certainly at no greater rate than the ice itself and almost certainly at a much slower one. We have no certain evidence what the progress of the glacier was, but it could not have been a rapid one. In existing glaciers the most rapid rate of motion is about seventy-five feet a day, but this occurs only during one or two months in summer, and in two or three exceptional Greenland glaciers where the ice, so to speak, is under pressure down a favorably

inclined valley from the great Greenland ice-cap, the nearest analogue to the immense glaciers of the drift period with which we have at present any satisfactory acquaintance. These rapid flowing glaciers are exceptional in Greenland, where the general movement of the ice is unquestionably very slow. They can be compared to rapids at the outlet of a lake. The Greenland ice-cap far overtops the bordering mountains, and yet in only some seventeen places along the whole Danish Greenland coast are there free outflows to the sea. While we know less of the other portions of the coast the general character is the same; a rapid motion is exceptional and it is a reasonable certainty—to quote Taylor[1] whose paper contains the latest discussion on this ice motion —"that the average movement of that portion of the border of the Greenland ice-cap that rests upon the land is extremely small. Of that portion which ends in the sea only a small fraction has a high rate of motion, as is shown by the lack of activity in the discharge of icebergs. When it is considered that the land border is very much greater than the sea border, and that of the sea border a portion has a relatively slow movement, it will be evident that the average rate of movement of the great ice-sheet of Greenland cannot be high; and the average rate of this border is the nearest available analogue to the border movement of the still more extended periphery of the ancient American or Laurentide glacier."

In fact it is impossible, when we consider that the Greenland ice-cap only abuts on the sea along a small portion of its border in the form of glacial tongues, and that the average movement of these is so small, not to believe that towards its interior the ice movement must be almost imperceptible—almost if not absolute stagnation. The Antarctic ice-cap is very little known to us, but its movement must also be very slow, judging from the discharge of icebergs. All the icebergs of the North Atlantic come practically from a few Greenland glaciers, making up altogether only a minute fraction of the whole Greenland coast. In the Antarctic, on the other hand, we know of hundreds of

[1] JOUR. GEOL. Vol. V, 442, 1897,

miles of continuous ice cliffs ending directly in water hundreds of fathoms deep, and have reason to believe that this is only a fraction of what exists, and yet icebergs are sometimes almost unknown in the southern seas for years at a time. Again there will be years in which they are abundant and extraordinary in size, but at no time is their quantity comparable to what ought to exist were the discharge anything like a free one along the barrier.[1] It can be reasonably assumed, therefore, from what we know at present that the movement of the southern ice-cap is also extremely slow, notwithstanding the favoring conditions of direct discharge into deep water.

The great Laurentide glacier, extending over four million square miles of surface, can also be safely assumed to have had a very slow motion as a whole, fully as slow as that of the Greenland or southern ice-cap. In fact the question arises, and is not at first sight readily answerable, how it had any motion at all. Gravitation certainly had less play than in Greenland, for instead of an area nowhere more than three hundred miles from the ocean [1] we have one eighteen hundred or two thousand miles in

[1] "As has already been stated, there are years of very few or no icebergs, and then years when great numbers are reported. In the year 1832, the southern ocean was so covered with icebergs that a number of whaling vessels, bound round Cape Horn, encountering them, put back to Valparaiso to await a more favorable season, because it appeared too dangerous to undertake the voyage. Again in 1854 there was a great accumulation of icebergs, and now during the past few years, notably 1892 and 1893, there has been another notable output from the great berg factories of the Antarctic regions. During the intervals between these periods there have been very few bergs reported. What causes this occasional great accession of bergs? Some authorities offer as a probable explanation the breaking off of the ice margin by volcanic eruptions, and others that earthquakes cause numerous pieces of the glacier to become detached and set adrift as icebergs, and others that unusual heavy annual snowfall is favorable for increase in number of bergs. The rapidity of glacier movement seems usually to regulate the number of bergs cast off. If the ice at the bottom of the glacier moves so slow that the melting of the margin on coming in contact with the salt water equals the advance, then we would have no icebergs, except perhaps those breaking off from the upper part of the outer margin, and these would be comparatively small." W. T. Gray, M. S. U. S. Hydrographic Office, Pilot Chart, N. Pacific Ocean, Nov. 1896.

[1] Prof. Chamberlin finds no evidence that the ice-sheet of Greenland ever very greatly exceeded its present limits.

diameter and one in which no reasonably supposable elevation could give a uniform slope varying appreciably from the horizontal. An elevation at the center of radiation of ten thousand feet (which is much beyond the most favorable interpretation which any known data will bear) with an ice-cap of as much more, would only make a slope of under half a degree in eight hundred miles, and of considerably less in some directions to the outer limits of the ice. Some glacialists, however, are liberal in their allowances of earth movement to account for the flow of the glacier. Mr. Upham,[1] for example, thinks that the strong current needed to transport bowlders from the southeast shore of Hudson Bay one thousand miles southwestward to southern Minnesota, would require a slope of at least fifty feet or more per mile, apparently unmindful of the fact that such a slope for the given distance would require an elevation of the ice-cap to the height of 50,000 feet, where precipitation would, if it occurred at all, probably be so slight as to seriously embarrass the formation of any considerable ice-cap whatever. It is not probable, however, that there was any uniform slope over the glacial field, and whatever effect was produced by gravitation could not be such as would cause a rapid motion of the ice, "faster than the Swiss glaciers."[2] The other theories that have been invoked for the glacier motion, the effects of thawing and freezing, expansion under varying temperatures, etc., are none of them, we think, counted as sufficient to cause rapid movement in so large a mass, as a whole, even by their upholders, and such estimates as two to five feet per day are hardly based upon a due consideration of the probable or possible physical conditions. Dana's[3] estimate that "the rate of motion could hardly have exceeded a foot a day, and may have been in most parts no more than a foot a week" is much more likely to be near the truth. Ice, except under special conditions of pressure or *vis a tergo*, barely moves on a slope of one degree, and an average slope

[1] Greenland Ice Fields and Life in the North Atlantic, p. 304.

[2] WARREN UPHAM. Bull. Geol. Soc. Am., III, 401, 1892.

[3] Geology, 3d ed , p. 539.

of a quarter of a degree for a thousand miles would require an elevation at the point of origin of the flow of something approaching five miles. The probability, and we may say the certainty, is that the slope was not uniform and that over large distances the ice traveled over dead levels, and in parts even stagnated, the upper part flowing over the lower débris-laden portions. That the contained débris has a retarding influence on the flow of glaciers has been urged by O. P. Hay,[1] I. C. Russell,[2] and R. D. Salisbury,[3] and it appears that this may even cause absolute stagnation under some circumstances. Even detached erratics seem to progress more slowly than the body of the ice in certain instances; witness the well-known observation of Professor W. H. Niles[4] on the Aletsch glacier where ice moved so much more rapidly than a contained bowlder as to leave a free tunnel for a considerable distance on its lee side. Even lighter substances appear to be occasionally retarded in their progress as compared with the ice. Recognizable remains of buried travelers have been taken out of Alpine glaciers even hundreds of years after their loss.[5] It is impossible, therefore, to claim that these erratics could have traveled at the same rate as the surface of the glacier, and when we consider that they bear the marks of having been subjected to scouring in the ground moraine that has left their surfaces flattened and striated, the probability of such a rate of progression is certainly very much diminished.

Allowing a flow of two feet per day to the ice-sheet, which is undoubtedly far above the real rate of the ice movement, it would require 7200 years for Mr. Upham's bowlder to travel its thousand miles from Hudson Bay to southern Minnesota, and this without any delay from friction or attrition in the ground moraine, or stagnation in the lower strata of the ice. Taking, also, into account the fact that the northern erratics are found at all dis-

[1] Am. Jour. Sci. and Arts, 3d ser., XXXIV, 52, 1887.

[2] JOUR. GEOL., III, 823–883, 1895.

[3] *Ibid.*, Vol. IV, 769–810, 1896.

[4] Am. Jour. Sci., 3d ser., XVI, 367, 1878.

[5] SIR HENRY HOWORTH. Geol. Mag. N. S., Decade IV, Vol. IV, 127.

tances from their point of origin and at all levels in the drift, it seems sufficiently clear that we cannot measure the duration of any single ice invasion by the period required for the transportation of a single erratic from its northern origin to its outer verge, even allowing for all the retardation in the ground moraine. Every one of the Archæan fragments so commonly seen along the southern borders or the drift must have required some four thousand years, even if we allow it to have advanced two feet a day, to reach its present position and probably a much longer period, for there is no good reason to suppose that the mass of the ice-sheet itself advanced at any such rate. We can also allow a somewhat more rapid transportation of débris near the margins by floods, subglacial drainage, etc., and yet find our time limit tending to be too small. The Alpine and Scandinavian glaciers, with their steep gradients affording full play to the action of gravity, move on an average only a few inches a day. How the continental glacier derived its movement, except at its elevated origin and near its periphery, is one of the questions that no one has yet satisfactorily answered, and the inevitable conclusion from the known facts is that while motion undoubtedly occurred it must have been extremely slow.

The formation of the ground moraine must have required a very prolonged period of time, involving as it did the grinding up and working over of the rocks and other material that together make up the till. It does not matter whether it is held that it was mainly deposited under the ice-sheet by stagnation of contained débris, as suggested by O. P. Hay,[1] or as a continuous terminal moraine as the glacier retreated, as was held by Newberry.[2] In either case a long time must have been required.

In what has been said I have tried to show that a great ice-sheet thousands of feet in thickness, extending over a third of a continent, expanding from its center in the direction of least resistance towards its periphery, having over the greater portion of its area a very slight slope, and probably none at all

[1] Loc. cit.

[2] Geol. Survey of Ohio, Vol. II, 29; III, 34.

in parts; hampered by inequalities of the underlying surface and by the detritus it shears off from these, must have had a very slow, though irresistible, progress; and that, accepting the existence of such an ice-sheet and taking account of this slow rate of progression, the contained erratics, whose origin can be identified by the situations in which they are found and the distances they have traveled, will afford a better means of making an approximate minimum estimate of the duration of the Pleistocene period than any other at our command. By this we can assure ourselves with almost absolute certainty that a single ice invasion could not have taken place carrying a single erratic from north of the lakes to the southern limit of the drift in less than four or five thousand years, and this without taking any account of the time required for the change of climate, the gradual gathering of the ice, its recession, the probable slower motion of the erratics than of the ice mass as a whole, or its retardation by friction, as evidenced by its facetted and striated surfaces. Taking all these into the reckoning, we ought, it would seem, to triple or quadruple the time; and if, instead of taking the highest estimates of glacier motion, we accept the more reasonable and probable ones, the period will be still more prolonged. It is difficult to see how, under these circumstances, a single ice invasion could have begun and run its course within the limits of less than thirty or forty thousand years; and if we accept Dana's estimate of the glacier flow at one foot a day for a maximum, and one foot a week as a possibility, we would have to carry our figures very much higher. We have, however, according to some of the highest authorities, Chamberlin, Leverett, and others, five separate ice invasions to account for, besides interglacial periods of possibly equal or greater duration; and this greatly magnifies the necessary estimate of time for the whole glacial period. One of these ice invasions appears to have transported bowlders one thousand miles, which, at the liberal rate of two feet per day, would require 7200 years, and the others, from the average extreme distance to which erratics were transported, will equal certainly 500 miles, which would require

3600 years, or, in the aggregate, 14,400 years. The total, therefore would be, in round numbers, about 22,000 years for the mere transportation of a single erratic in each invasion, and that at an improbable rate of speed and without any allowance whatever for the time occupied in the formation, culmination, or retreat of the glacier, or for interglacial periods. It is sufficiently evident from these figures that the ice-sheet theory of the till formation is utterly incompatible with such estimates as those of Prestwich and Wright, which give the whole glacial period a duration of only 20,000 to 40,000 years.

It has been matter of surprise to me that so little weight has been given by authorities to the arguments from the calculation of the transportation of erratics in the estimation of the duration of the glacial period. Most of them absolutely ignore, or at least fail to utilize it, and those who do allude to it at all, like Helland,[1] give it only the briefest and most casual mention. It appears to me to be the one method by which we can obtain, not the actual, but the utmost possible minimum of duration of such an ice-sheet as the generally accepted glacial theory demands.

Professor W. J. Crosby[2] has offered the suggestion that, as the great mass of the rock débris of the till is local and has never traveled far from its place of origin, the northern erratics were transported largely by water in the glacial lakes that formed along the borders of the ice-sheet. Inasmuch as these are found throughout the till at all levels, his suggestion amounts practically to an admission that the whole mass in which they are disseminated was thus deposited, which is altogether inconsistent with the general tenor of his argument, and is almost, if not quite, equivalent to giving up the land-ice theory of the deposition of the till.

It may be worth while here to notice one or two estimates or statements in regard to the duration of certain stages of the glacial period by prominent glacialists. The recent estimate of

[1] Zeitschr. der deutschen Geologischen Gesellsch. XXXI, p. 76, 1879.

[2] Am. Geologist, XVII, 1896, p. 234.

F. B. Taylor of from 75,000 to 150,000 years for the recession of the Wisconsin ice-sheet from Cincinnati to Mackinac has been already alluded to in the early part of this paper. As against this apparently large, but possibly not too large estimate (that is, admitting the land-ice formation of the Wisconsin drift), it is interesting to quote Wright and Upham's[1] dictum that "the late divisions of the glacial period were far shorter than its Kansan, Aftonian and Iowan stages," and the estimate of Chamberlin[2] that makes the ratio of time to the present from the earliest Wisconsin and from the Kansan stages as 2½ and 15 respectively, leaving an undetermined figure for the still earlier portion of the glacial period. That would make, according to Taylor's figuring of 150,000 to 300,000 years for the Wisconsin invasion and retreat, a period of somewhere between 900,000 and 1,800,000 years back to the beginning of the Kansan drift. These figures are, it is true, rather staggering, but it is not absolutely necessary to accept the two estimates and combine them. There may be other ways of reckoning the duration of the separate stages of the drift. Certain it is at least that neither of these authors is to be held responsible for the estimates of the other, or the combination of the two.

In conclusion, the reasoning of this article may be summarized as follows:

The estimates of the duration of the glacial period by prominent geologists vary almost as widely as possible. It is probably useless to attempt to obtain any approximate estimate of its maximum duration, but we have in the transportation of erratics a simple method by which an ultimate minimum of the time occupied may be obtained. Accepting the land ice hypothesis of the deposition of the till, we must from all analogies, and all our knowledge of glaciers and ice-caps, admit that the motion of the ice-sheet was slow, and that it probably did not exceed a few inches a day; indeed, apart from the evidence of the till and its contained erratics, it is hard to find any grounds for belief in its motion over large proportions of the occupied territory. Erratics

[1] Loc. cit., p. 360. [2] Loc. cit.

that are known to have been transported distances of from 500 to 1000 miles could not have traveled faster than the main body of the ice, and must, as we know from the evidences they bear of retardation and friction, have traveled much more slowly. Even allowing the extravagant estimate of two feet *per diem* for the ice movement throughout (and the recent investigations of Chamberlin and others on the Greenland ice-cap have demonstrated that this is an improbability) we can demonstrate that a single invasion competent for the transportation of a single erratic from its northern source to the southern limits of the drift would have required a period of from 15,000 to 20,000 years.[1] If we admit, as is more reasonable, that the average ice motion was much less than this,—probably not over a very few inches *per diem*, we will have to more than quadruple this estimate. Taking into account, however, the inevitable conclusion that the duration of a single ice invasion was not limited to the conveyance of a single erratic or simultaneous group of erratics, and that there were, in all probability, several of these invasions with intermediate periods of sufficient length to allow the development of extensive forests and the accumulation of heavy deposits of vegetable mold, indicating a lapse of probably many thousand years, we are compelled to multiply the above figures by an indefinite multiplier. The outcome in any case is that the brief duration allowed for the glacial period by some recent authorities is absolutely incompatible with the evidence of erratics, according to the land ice or glacier theory of the deposition of the drift.

[1] I have not in my argument taken account of the slowness of advance of the ice border which must also be considered in calculating the total. Opposed to each year's advance there must have been a summer's melting, and judging from the evidence of the Greenland ice-cap, this latter element must have been of considerable importance. The Greenland ice-sheet hardly gains at all upon the unoccupied land even in North Greenland, the ice surplus all escaping by the few glacial outlets which are much less active than those in South Greenland. In the case of the Laurentide glacier trenching upon a fairly temperate region with a long summer, the estival melting must have been quite marked. The additional transportation by flood torrents, etc., can be estimated by the extent of the till deposits as compared with glacial striæ, which even in southern Illinois are reported as found on the underlying rocks nearly to the southern margin of the drift.

I have not attempted in this article to exhaustively discuss the evidence of the slow motion of the ice in the Laurentide glacier. Much more could have been said on that point, but anyone who has followed the recently published studies of glacial phenomena in Greenland by Chamberlin, Salisbury, and others, will be able to supply most of the deficiencies in my argument. The present paper is simply the statement of views that were suggested by a consideration of some aspects of the glacial theory as an amateur geologist.

I wish to also acknowledge here my indebtedness to Professor T. C. Chamberlin for valuable suggestions on certain points here discussed.

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